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A Feasibility Study on the Thermal Effluents Energy Business Model of Nuclear Power Plants

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***Abstract*—Seawater used to cool thermal energy generated during the power generation is thrown into the sea at a temperature about 7~10℃ higher than the natural water temperature, which is called Thermal Effluents (TEs). The domestic TEs amount is 56.3 Billion tons per year, which is an energy source with abundant potential to reach 394,775 Tera calories per year. However, the problem is that TEs cause not only thermal pollution, but also waste of energy. So, we derive the needs for the TEs Energy Business Model (TEs-E BM) of Nuclear Power Plant (NPP) through analysis of the potential energy reserve amount of NPP's TEs among power plants. Then, we design a TEs-E BM that can be applied immediately to reality, and then validate the feasibility of the TEs-E BM of NPPs by analyzing it based on the current laws and support systems, technology and economics. Additionally, we suggest the improvement of the current support system in order to further activate the utilization of TEs energy. Based on the results of this study, KHNP, the only NPP company in Korea, will be able to maximize the status of fulfillment of Renewable Portfolio Standard obligations economically and also minimize thermal pollution**

Keywords—Thermal effluents; NPP (Nuclear Power Plant; LCOE (Levelized cost of energy); RPS; REC; KHNP

I. INTRODUCTION

When you look at the sea around the power plant, it is easy to notice that the color of seawater is different across a certain area. It is a phenomenon that water mass appears temporarily because seawater around the power plant is warmer than the surroundings. This phenomenon occurs because seawater used to cool thermal energy generated during the power generation is thrown into the sea at a temperature about 7~10℃ higher than the natural water temperature. We call the seawater used to cool thermal energy as Thermal Effluents (TEs). This topic is important because it is a waste of energy as well as destruction of marine ecosystems due to thermal pollution. The domestic TEs amount is 56.3 Billion tons per year (Bton/yr), which is an energy source with abundant potential to reach 394,775 Tera calories per year (Tcal/yr). If it is reused as a heating source in various fields, it can improve efficiency of energy utilization, replace energy import, and reduce greenhouse gas emissions.

Previous studies [1-6] in Korea are divided into two groups before and after TEs energy is included in new and renewable energy through the amendment of "Enforcement Decree of the Act on The Promotion of the Development, Use and Diffusion of New and Renewable Energy" on April 4, 2015. The common point between two groups is that they were not focused on TEs of Nuclear Power Plants (NPPs) but on those of Thermal Power Plants (TPPs). Especially, studies after law amendment focused on economic analysis through comparison with other new and renewable energy based on the government support systems to activate TEs energy [5, 6]. Those studies are based on the assumption that a preliminary consumer in rural area who wants to use TEs energy will develop it directly. However, the private sector in the present farming and fishing villages still has a difficulty developing directly due to the small economic power. Considering this situation, previous studies were aimed at business developers who could not carry out business realistically, and the results of previous studies also could not be applied to the reality.

No experimental study suggesting concrete and instantly feasible business model for the power plant company has been reported to our best knowledge about TEs energy. Therefore, unlike previous studies, this study considers Korea Hydro & Nuclear Power Co., Ltd (KHNP), one of the heat producers with abundant financial resources and the only Nuclear Power Plant (NPP) company in Korea, as a developer, instead of a heat consumer with poor financial resources. By doing so, this study is different from previous studies because we utilizes NPP's TEs instead of TPP's TEs, and also utilizes the actual heat load instead of the virtual heat load. If the business model created under these conditions is validated through this study and can be practically utilized in KHNP's TEs energy development, it can contribute to the activation of NPP's TEs energy in Korea.

Therefore, this paper is composed as follows. Section 2 presents the overview and status of utilizing TEs in Korea such as the energy reserves of TEs, and the current laws and support systems of the government. In Section 3 this study propose the Thermal Effluents Energy Business Model (TEs-E BM) of NPPs and sets up an economy evaluation method for it. We analyze the economic feasibility of the TEs-E BM of NPPs according to the set method in Section 4. Finally, this study suggests the improvement of the current support system of the government to further activate the TEs-E BM of NPPs in Section 5, and then concludes in the last section.

II. OVERVIEW AND STATUS OF UTILIZING THE THERMAL EFFLUENTS

A. *Energy Reserves of Thermal Effluents*

In order to derive the needs for the development of the TEs-E BM of NPPs, we analyze the potential energy reserve amount of NPP's TEs. As presented in Table 1, although the annual

TEs energy of TPPs and NPPs is similar, the result shows that the annual TEs energy per site of NPPs is higher than TPPs.

TABLE I. DISCHARGES AND RECYCLED AMOUNT OF THERMAL EFFLUENT IN 2014

Power Companies	KHNP(NPP)	5 Companies(TPP)
Number of Site	4	20
Thermal efficiency [%]	34~36	39.33
Temperature difference between TEs and seawater (ΔT) [°C]	7	7
TEs discharge (W) [Bton/yr]	27.736	28.618
TEs discharge (W) per site [Bton/yr·site]	6.934	1.431
Heat reserves (E) [Tcal/yr]	194,152	200,326
TEs energy (Eh) [Tcal/yr]	268,826	277,374
TEs consumption [Bton/yr]	0.0049	1.94

In order to calculate TEs energy, we should know the TEs temperature and the TEs discharge.

As for the TEs temperature, according to the Korea Environmental Institute (2013) [7] and the real-time temperature of TEs of NPPs as of September 1, 2016 at 15:30 [8], the average ΔT which is the temperature difference between TEs and seawater is 5.8 to 8.9°C at most power plants as the season changes as in Fig. 1. However, if we compare ΔT in September, this result implies that ΔT of NPPs is higher than that of the most power plants because the thermal efficiency of NPPs is lower than that of the TPPs. This result shows that ΔT of the power plant is controlled not only by interlocking with the natural water temperature but also influenced by the thermal efficiency of the power plant.

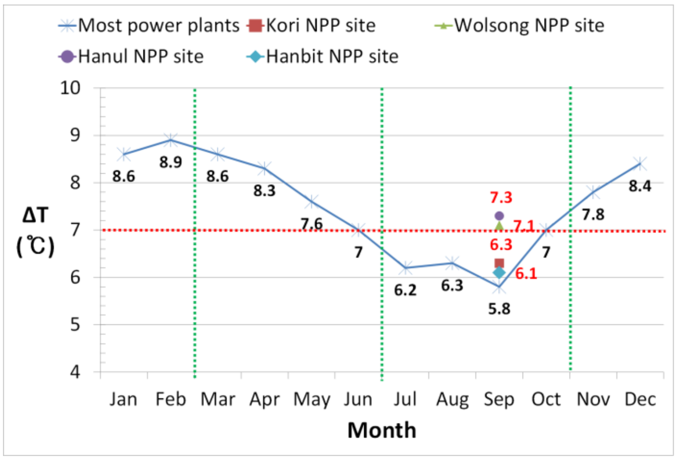

Fig. 1. Monthly ΔT Change of TEs

This is because most of the thermal energy remaining after the electricity generation in most power plants in Korea is discharged through the condenser into the sea in the form of TEs. On the steam turbine side, NPP uses the Rankine thermodynamic cycle with steam temperatures at saturated conditions. This gives the lower thermal efficiency than TPP. With this principle, the bituminous coal fired plants in Korea ran at 39.33% thermal efficiency in 2010 [9]. On the other hand, NPPs have about 34~36% thermal efficiency [10]. However, although ΔT values vary depending on water temperature and thermal efficiency, this study applies ΔT as the minimum standard of 7℃ [11] in order to prevent excessive calculation of the heat reserves.

As for the TEs discharge, 24 NPPs in Korea are currently operating at 4 sites by KHNP. The amount of cooling seawater used in a 1,000MW NPP is about 50~60 tons per second [12], and the annual TEs discharge of NPPs at 4 sites is 27.736Bton/yr in 2014 [13]. In contrast, in major 5 TPP companies using cooling seawater, the annual TEs discharge of TPPs at 20 sites is 28.618Bton/yr in 2014 [13]. In other words, NPPs discharge a larger amount of TEs per site than TPPs.

Heat reserves can be estimated by using the above obtained the TEs temperature and the TEs discharge for available capacity in terms of the heat source, and the basic formula of thermodynamics can be applied as shown in (1) [5, 14]:

$$E = \Delta T \times C \times W \tag{1}$$

Where, E: Heat reserves [Tcal/yr], ΔT = 7 [℃] as Temperature difference, C: Specific heat=1.0 [kcal/kg·℃], W: Annual average discharge of TEs [Bton/yr]

From the calculation result, the total energy reserve in Korea is determined to be 394,478Tcal/yr.

In addition, if the heat reserves are used for heat sources, we can produce TEs energy by using by using the heat production facility with Coefficient Of Performance (COP). TEs energy can be obtained by (2).

$$E_h = E \times \left(\frac{COP}{COP-1}\right) \tag{2}$$

Where, Eh: Thermal effluents energy [Tcal/yr], COP: 3.6 as the legal minimum performance standard

From the calculation result, the total Thermal effluents energy generated by KHNP and 5 major TPPs companies is 546,200Tcal/yr. Here, although COP values vary depending on the heat pump capacity, we applied the legal minimum performance standard of 3.6 in order to prevent excessive calculation of TEs energy.

As presented in Table 1, there is 564Bton/yr of TEs discharged annually by KHNP and 5 major TPPs with a potential TEs energy of 546,200Tcal/yr available for heating as of December 2014, but most of them are discharged to the sea and only about 1.9Btons/yr (0.35%) are being recycled in fish farm and greenhouse [13]. In particular, although the annual TEs energy of TPPs and NPPs is similar, the annual TEs energy per site of NPP is higher than TPP. Therefore, this finding indicates that NPPs have more favorable environment conditions for TEs energy development than TPPs in terms of reducing investment costs in developing large-scale TE energy projects. However, despite such NPPs' favorable environment conditions for TEs energy development, the TEs consumption of NPPs (0.0049Bton/yr) is very low compared to that of TPPs (1.94Bton/yr). This is why we need to develop the TEs-E BM of NPPs unlike previous studies.

B. *Current laws and support systems*

In order to derive the needs for the development of the TEs-E BM of NPPs, we also analyze the current laws and support systems.

As for the laws, according to the recently amended "Enforcement Decree of the Act on The Promotion of the Development, Use and Diffusion of New and Renewable

Energy (Amended, April 4, 2015)", TEs energy of the power plant is equivalent to "Hydrothermal energy" among new and renewable energy source. In more detail, the standard of hydrothermal energy is defined as "energy obtained by converting the heat of the surface layer of water by using a heat pump ". In other words, only TEs energy generated by the heat pump is limited to new and renewable energy. In addition, under the same law, there is Renewable Energy Portfolio Standard (RPS) system that mandates the supply of new and renewable energy to a power generation company with a certain scale (500MW) or more of power generation facilities excluding new and renewable energy facilities. So, generation companies with power generation capacity of 500MW or more (hereinafter referred to as "mandatory supplier") must mandatorily supply at least a certain amount of electricity generated by using new and renewable energy (hereinafter referred to as "RPS obligation") every year. Therefore, power generation companies that discharge TEs can utilize TEs energy as a new and renewable energy source to fulfill the RPS obligations. Through this, it is also expected that it will be possible to comply with emission temperature limit, which is below 40°C, at the same time according to "Water Quality and Aquatic Ecosystem Conservation Act".

As for the support systems, the Korean government also provided the support systems for promoting TEs energy business. The support systems are largely divided into the subsidies for capital investment costs and the issuance of Renewable Energy Certificate (REC) for new and renewable energy production. REC is a certificate certifying that a power generation company has produced and supplied electricity using new and renewable energy facilities, and issued by Korea Energy Agency. Assuming the impossibility of applying the subsidies and the issuance of REC at the same time, the issuance of REC is more attractive than the subsidies for power generation companies with a wealth of financial resources. For this reason, this study applies only the issuance of REC by "Guidelines for management and operation of RPS" in the support systems. It assigned a weight of 1.5 to the REC when TEs energy is used as energy for agriculture and fishery

$$R = W \times P \tag{3}$$

Where, R: REC approved power generation volume [MWh], W: REC weight, P: New & Renewable energy generation [MWh]

For example, if a power generation company supply 1MWh of TEs energy to agricultural and fishery, it can obtain REC of 1.5MWh, which is 1.5 times the supplied energy by (3).

Based on these laws and support systems, Table 2 shows the amount of mandatory supply with deferment and status of fulfillment of obligation of KHNP that is the largest mandatory supplier under RPS in Korea.

TABLE II. RPS PERFORMANCE OF KHNP

Year	KHNP's amount of mandatory supply with deferment [MWh]	Status of fulfillment of RPS obligation [MWh]	Deferment [MWh]	RPS failure [MWh]
2012	2,010,256	1,624,287 (80.8%)	385,969 (19.2%)	0
2013	2,848,701	2,156,467 (75.7%)	692,234 (24.3%)	0
2014	3,122,315	2,185,620 (70%)	936,694 (30%)	0
2015	3,419,315	2,735,452 (80%)	683,863 (20%)	0
2016	3,415,090	2,732,072 (80%)	683,018 (20%)	0
2017	3,492,424	-	-	-

Fortunately, there were no failures to perform duty to supply new and renewable energy (hereinafter referred to as "RPS failure") until 2016. But there were no detailed data exposed to public since 2014. So, this study assumes the amount of deferment is calculated by applying the maximum limit of 20% or 30% from 2014. This is because a mandatory supplier may defer the performance of a duty to supply some of the amount of mandatory supply for a period not exceeding three years up to 30% by 2014 and up to 20% after 2014. As a result, if KHNP doesn't develop directly new and renewable energy or purchase REC, they may have to pay the penalty surcharges for RPS failure due to the cumulative increase of the amount of mandatory supply every year.

However, as the abundant TEs energy of NPP is designated as new and renewable energy by law, if KHNP develops directly TEs energy, the result can be shown in Table 3.

TABLE III. TES ENERGY UTILIZATION RESULTS UNDER THE CURRENT LAWS AND SUPPORT SYSTEMS

Contents	Value	Notes
KHNP's amount of mandatory supply with deferment in 2014 [MWh/yr]	3,122,315	
TEs discharge [Bton/yr]	277.36	
TEs energy [Tcal/yr]	268,826	COP: 3.6
Estimated power generation [MWh/yr]	116,880,803	Equation(4)
Estimated REC [MWh/yr]	175,321,204	Weight: 1.5
Fulfillment rate of RPS obligation	56	

Here, we use (4) to calculate REC based on the "Energy Calorie Conversion in Criteria of the Enforcement Rule of Energy Act (Amended, Dec. 30, 2011)".

$$P = (C \times 0.1) / 0.23 \tag{4}$$

Where, P: New & Renewable energy generation [MWh], C: TEs energy consumption or production [Gcal/yr]

Assuming that 100% of the generated TEs energy is consumed, the conversion from TEs energy which is 268,826,846 Giga calories per year (Gcal/yr) in Table 1 to New & Renewable energy generation is 116,880,803MWh/yr by (4). Moreover, according to (3), REC approved power generation volume is up to 175,321,204MWh. KHNP's amount of mandatory supply in 2014 was 3,122,315MWh including the deferment in 2013. Therefore, the annual fulfillment rate of RPS obligation that can be achieved when converting the whole amount of the annual TEs energy to REC is 56 times. This findings show that it is necessary for KHNP to utilize a TEs-E BM under the current laws and support systems.

III. ECONOMY EVALUATION METHOD OF THE THERMAL EFFLUENTS ENERGY BUSINESS MODEL OF NPPS

A. Case Study Area

In order to minimize the uncertainty of demand, this study is based on not the virtual demand but the real demand which reflects the situation around the NPP site, unlike the previous study. So, in this paper, we analyzed the demands that can consume thermal effluents energy within 2km radius from Wolsong NPP site in Gyeongju city

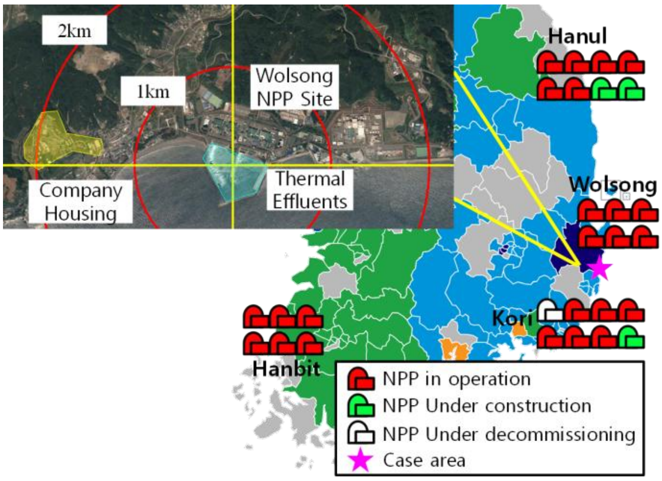

Fig. 2. Case study areas and NPP sites location in Korea

Fig. 2 shows the location of NPP sites in Korea and the case study areas showing the nearby situation. Actually, there were no large-scale agricultural lands near all NPP sites. This is because the neighboring areas have not been developed due to the dislike of NPP, and it seems that heating demand has not been formed in the end. So, the residential heating load of Wolsong NPP company housing that requires massive heating energy is selected inevitably and analyzed as a demand of thermal effluents energy for this study.

B. Economics Evaluation Method: Levelized Cost Of Energy (LCOE)

The LCOE [15] is a useful tool for comparing the unit costs of different technologies over their operating life. The LCOE methodology was developed in a period of regulated markets. Korea is in the stage of running the market through the Cost-Based Pool (CBP) that reflects variable costs during the development stage [16]. Therefore, this study compares and analyzes the economic feasibility among different technologies through the LCOE reflecting the characteristics of the Korean power market [17].

Conceptually, The LCOE is simply the total cost of a project over its lifetime divided by the total amount of energy produced or the total amount of power generated during that period as (5). Here, this study uses the currency of South Korea as cost unit and marks it as “won”.

$$LCOE = \frac{Lifecycle\ cost}{Lifetime\ energy\ production}[\text{won/kWh}] \qquad (5)$$

This includes the process of presenting all elements using a discount rate taking into account the time value. This study utilizes the modified and supplemented LCOE estimation method of the power supply and demand basic plan in Korea based on the OECD/IEA's LCOE estimation methodology [18]. The overall methodology is the same as the OECD/IEA's LCOE estimation methodology, but it is characterized by the facts that the corporate tax and onsite consumption ratio are additionally considered and that the variable operation maintenance cost is not considered separately.

The LCOE varies depending on factors or variables considered in the estimation process. Also, depending on which formulas are used, the results are sensitive. Therefore, it is necessary to consider the same factors and to apply the same formulas collectively when comparing characteristics of different energy system.

In addition, based on the status of new and renewable energy projects which KHNP is developing for RPS obligation in Korea, this study selects solar power system and wind power system as the comparative new and renewable energy system [19].

C. Description of Total Framework

Based on the the case study area, we create the TEs-E BM of NPPs as in Fig. 3 that can be applied immediately to reality for economic analysis. The TEs-E BM consists of heat source, heat consumer, and TEs energy system. The energy flow through the TEs-E BM is as follows: 1) Heat recovery devices are installed in heat source. 2) The heat recovery water is then delivered to the heat pump through the pipes, which increases the water temperature to 40~90 ℃ to store in a heated storage tank. 3) The stored water is used for heating consumer which are company housing and greenhouse heating. Since the analysis of the heat source is done in Section 2, we have only to analyze the heat consumer and the TEs energy system. Here, for the simplification of the TEs-E BM, we assume that the heat source is obtained by using the TEs tank or pit regardless of the TEs discharge method.

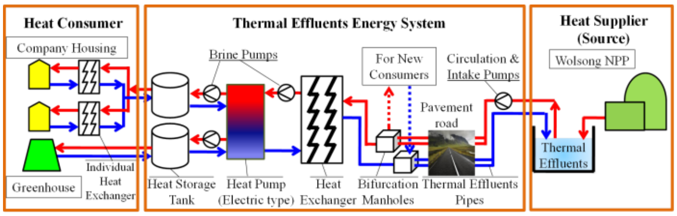

Fig. 3. Structure of the TEs-E BM for NPPs

IV. ECONOMY ANALYSIS OF THE THERMAL EFFLUENTS ENERGY BUSINESS MODEL OF NPPS

A. Heat Consumer Analysis

The company housing in Wolsong NPP site owns 1200 households, and currently uses Liquefied Petroleum Gas (LPG) or midnight power service for heating, which is relatively expensive compared to urban gas and district heating in urban areas. In addition, it is impossible to obtain heating load data for each household due to the different fuel supply methods such as LPG, and various voltage supply systems. In order to ensure a quantitative energy analysis, the heating load pattern analysis should be carried out using KEPCO's Station Operation Result Management System (SOMAS) [20]. As a result, for the 360 households of Wolsong NPP company housing using midnight power service, we analyze the SOMAS data during the 3–year (2011~2014) winter season (November~April) nighttime (23:00~09:00) to estimate the heating load.

We can get the maximum power peak load for heating and the annual heating power consumption through the company housing load analysis.

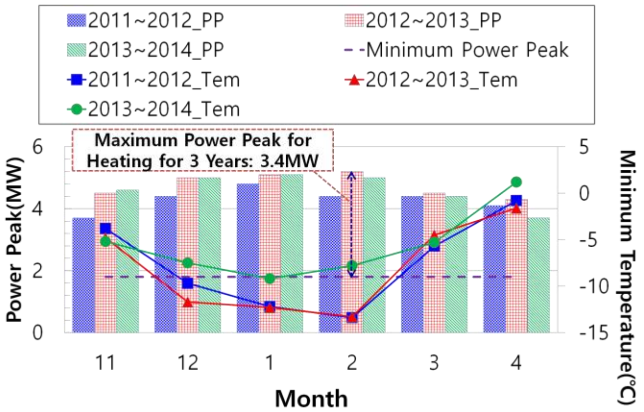

Fig. 4. Power peak for heating for 3 years

First, the maximum power peak for heating performance was analyzed to estimate the capacity of the TEs energy system. Fig. 4 shows the daily power peak performance from SOMAS. Maximum power peak for all loads is 5.2MW on Feb. 7, 2013. If we assume that the minimum power peak of 3 years is the maximum power peak for base load, the maximum power peak for base load is 1.8MW on Sep. 18, 2013. As a result, if we assume that the difference the maximum power peak for all loads and the maximum power peak for base load is the maximum power peak for heating, it is 3.4MW during the 3-year winter season nighttime.

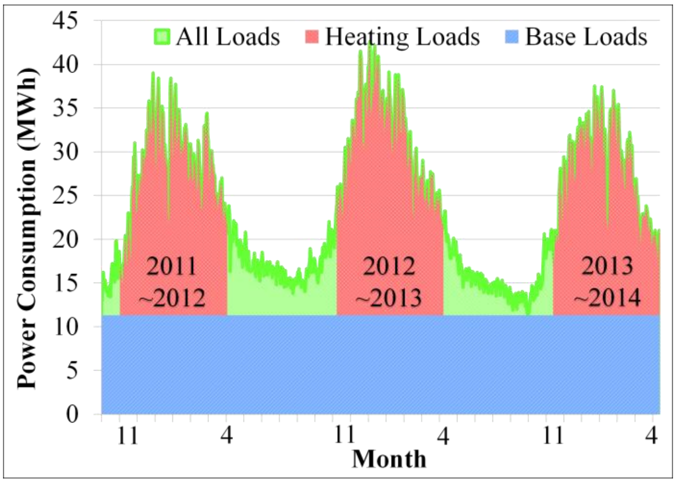

Fig. 5. Average annual heating power consumption for heating for 3 years

Next, annual heating power consumption is analyzed to calculate the capacity factor of the TEs energy system. Fig. 5 shows the annual power consumption from SOMAS. For 3 years, power consumptions for all loads during winter nighttime were 5,119MWh/yr, 5,623MWh/yr, and 5,034MWh/yr, respectively. If we assume that the minimum annual power consumption is assumed to be the power consumption for base load, daily power consumption for base load was 11.3MWh/d on Sep. 9 in 2013. From the analysis in Fig. 5, Table 4 shows the annual power consumption for heating during the 3-year winter season nighttime.

TABLE IV. POWER CONSUMPTION FOR HEATING DURING THE WINTER SEASON

Year	**Monthly Power consumption for heating during the winter season (MWh/mon)**						**Yearly Power consumption for heating during the winter season (MWh/yr)**
	Nov.	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	
2011 ~ 2012	**287**	**604**	**632**	**566**	**537**	**425**	**3,051**
2012 ~ 2013	**495**	**772**	**787**	**633**	**494**	**396**	**3,578**
2013 ~ 2014	**398**	**622**	**642**	**564**	**468**	**296**	**2,989**

As a result, the average annual power consumption for heating during the 3-year winter season nighttime is 3,206 MWh/yr.

Finally, the analysis results of real residential heating load for 360 households at Wolsong NPP company housing can be shown as Table 5. In fact, the company housing consists of 2 complexes, the first one, which is 650 households, is located 2km away, the second house, which is 550 households, is 9km away. In this study, we estimated 1200 households as the heat consumers considering the company housing complex that is created when developing a new NPP site.

TABLE V. ANALYSIS RESULTS OF RESIDENTIAL HEATING LOAD

Total number of households	360	1,200
Average floor area [m^2/household]	59	
Annual average power consumption for heating per unit area [kWh/ m^2]	150.93	
Maximum power peak for heating per unit area [W/ m^2]	160.08	
Annual average power consumption for heating [kWh/yr]	3,205,650	10,685,500
Maximum power peak for heating [kW]	3,400	11,333

As a result, when the actual heating load for 360 households is converted to the heating load for 1200 households, the maximum power peak for heating is 11,333kW and the average annual power consumption for heating is 10,685,500kWh/yr.

We also add a heat consumer for agriculture using the same heat production facility near Wolsong NPP company housing to increase the Capacity Factor. 10ha (8,775kW) of greenhouse presented in Rural Research Institute (2015) [5] is used as a heat consumer. If we add the heat pump operation hours (11:00 ~21:00) for greenhouse in addition to the heat pump operation hours (23:00~09:00) for Wolsong NPP company housing, the Capacity Factor increases from 10.76% to 17.58% without additional facility investment except for an additional heat storage tank. Therefore, the average annual power consumption for heating also increases from 10,685,500kWh/yr to 17,450,726kWh/yr

B. *TEs energy system Analysis*

Based on Fig. 3 and Table 5, we design the TEs energy system to supply TEs energy to the heat consumer 2 km away from Wolsong NPP as presented in Table 6

When COP of the heat pump is 3.6, one heat pump of 11,333 kW is needed to supply maximum power peak for heating. However, we add a heat storage tank to reduce the capacity of the expensive heat pump which means the burden of maximum power peak for heating. As a result, we can reduce the heat pump capacity to 6,800kW by adding 2 units of heat storage tank of 3,899m3/day and 3,019m3/day, which can store 40% of maximum power peak for heating. In addition, the heat pump is divided into two 3,400kW units to prepare for a failure, ensuring safety.

This study selects an underground landfill method for the TEs piping. According to the previous study [5], if the flow rate over a certain scale is continuously flowing at a diameter of 400 mm or more, the temperature drop from the heat source of TEs to 10km is less than 1°C regardless of the type of underground pipes. Therefore, this study use a high density poly ethylene (HDPE) pipe which cost less than the double insulated pipe.

In order to provide maximum power peak for heating load 9,747Mcal/hr, TEs should carry a mass flow rate of 1,005,608kg/hr. For this, the flow rate of 2.17m/s is required when selecting 400mm diameter TEs pipe. As a result, 2 sets of 422kW intake pumps are applied to the intake pipe line, and 1 set of 30kW circulation pump is applied to the intake pipe line and the discharge pipe line respectively.

TABLE VI. CONFIGURATION OF TES ENERGY SYSTEM

Configuration		Application	Unit
System capacity		11,333 (9,747)	kW (Mcal/hr)
Temperature difference between TEs and seawater		7	℃
Brine temperature difference		10	℃
Heating supply calorie		9,189,530	Mcal/yr
Heat pump	Electric type	3,400kW × 2	unit
	COP	3.6	
Heat storage tank	Volume (housing)	3,899m^3/d × 1	unit
	Volume (greenhouse)	3,019m^3/d × 1	unit
	Capacity	40	%
Heat exchanger		Plate Type, Titanium × 1	unit
TEs pipe (underground landfill)	Material	HDPE	
	Diameter	400	mm
	Length	2line × 2	km
Circulation pump	Power	30kW × 1	set/intake line, set/discharge line
	Transfer distance	2	km
Intake pumps	Power	422kW × 2	Set/intake line
Brine pump	Power	3kW × 2	set

C. *LCOE Analysis*

1) *Preconditions and Considerations for the LCOE*

The factors required to calculate the LCOE are Capital Investment Cost, O&M Cost, Fuel Cost, Total Supply Energy, Discount Rate, Economic Life and etc. So, we set the standard of the LCOE calculation first as in Table 7.

The economic life time of all new and renewable energy is commonly applied for 20 years for comparison convenience. The discount rate applied to the KDI public investment project discount rate of 5.5%. Moreover Domestic Producer Price Index (PPI) for power, gas and water sector is -5% [21], and overseas PPI is 0.4% [22] in 2015 compared to 2013. This does not reflect the reality, so the inflation rate is not taken into account when utilizing the initial investment cost within 3 years before the estimation date. The owner's equity ratio is 50% of the international standard value. Expected Rate of Return Capital is replaced by Discount Rate. The Constant Amount Method is applied to the Depreciation Rate.

The capital investment cost of the TEs-E BM is limited to the cost of installing TEs energy system except for the customer facilities installed for the heating. In addition, it is difficult to calculate the accurate capital investment cost because there are few cases of installation of the TEs energy system. Based on the configuration of TEs energy system as in Table 6, this study estimates the capital investment cost by referring to government-provided criteria, the rough construction cost presented in Rural Research Institute (2015), and the approximate construction costs of KEPCO (2015). However, it may be possible to show the difference of the capital investment cost when applying the different estimation standard for the same size system. In case of construction cost related to various facilities, this study applies Power Factor of Six-tenth Rule (Applied P=0.6, CSF=1.17) to equipment cost as well as equipment construction cost [23]. In particular, in case of the TEs piping construction cost, the construction cost is increased by applying pavement condition instead of an off-road condition in order to apply permission for occupation of road rather than the land purchase. However, instead of land purchase cost, applying charge for exclusive use of road during the economic life results in construction cost savings of 3% [24]. In conclusion, the capital investment cost of the TEs-E BM is estimated to be 6,428 million won when TEs is transferred through the underground HDPE pipe and stable supply of heating energy is provided to Wolsong NPP company housing 2 km away from Wolsong NPP.

The fuel cost of TEs-E BM is electric charges for driving the heat pump and various pumps. When selecting an Industrial Service (B)/High-Voltage A/option Ⅰ in Electric Rates Table of KEPCO [25], the fuel cost is estimated at electric charges 68.49won/kWh by combining the demand charge by KEPCO contract demand of 6740kW and the energy charge by annual heating use.

Since there is no existing commercial TEs-E BM, this study selects the reference models with the lowest O&M costs and similar to the TEs energy system of this study to estimate O&M cost. The O&M cost of the TEs-E BM applies the average O&M cost of the reference models, and is adjusted by applying the cost scaling factor with p-value 0.55 [26] when the system capacity is different. As a result, the O&M cost is estimated at 627 million won/yr by applying Cost Scaling Factor 1.09 to the average operation cost of 576million won/yr of Nam Tae Sup (2016) and Kim Kwang Gyu (2016) [6, 27].

TABLE VII. STANDARD OF THE LCOE CALCULATION

Types	TEs	Solar Power	Wind Power
Estimation Date	2015		
Discount Rate [%]	5.5		
Borrowing Rate[%]	100		
Life Time[yr]	20		
Exchange Rate[won/$]	1,095		
Owner's Equity Ratio[%]	50		
Expected Rate of Return of Capital[%]	5.5		
Comprehensive Corporation Tax Rate[%]	24.2		
Depreciation Rate	1/ Life Time		
Heat Supply Distance [km]	2	-	-
Capacity Factor[%]	17.58	15	23.13
Onsite Consumption Ratio[%]	0	0	0.8
System Capacity[MW]	11.4	20	20
Total Energy Consumption or Supply [MWh/yr]	17,451	26,280	40,200
Capital Investment Cost [million won]	6,606	57,360	49,880
Fuel Cost [million won/yr]	1,164	0	0
O&M Costs [million won/yr]	627	574	1,247

On the other hand, the capital investment cost, fuel cost, O&M cost of the solar power system and wind power system, which are the comparative system, are also estimated by the unit installation cost, fixed cost, and variable cost based on the major preconditions and assumptions for solar power LCOE estimation and wind power LCOE estimation of 20MW systems proposed by the Korea Energy Economics Institute (2014) [28].

2) *Result of LCOE Analysis*

Table 8 shows the result of the LCOE by applying the preconditions and considerations as shown in Table 7 and using the present worth analysis techniques.

TABLE VIII. RESULTS OF THE LCOE

Classification	TEs	Solar Power	Wind Power
Fixed Cost [won/kWh]	69.35	268.68	140.57
Capital Investment Cost [won]	6,606	57,360	49,880
Capital Recovery Factor [%]	8.37	8.37	8.37
Equivalent Corporate Tax Rate [%]	0.46	0.46	0.46
O&M Cost Rate [%]	9.49	1	2.5
Variable Cost (Fuel cost) [won/kWh]	66.72	0	0
LCOE [won/kWh]	136.07	268.68	140.57

The LCOE of the TEs-E BM is 136.07won/kWh, which is the lower than the LCOE of the wind power system (268.68 won/kWh) and the solar power system (140.57won/kWh). It means that the TEs-E BM of NPPs can perform RPS obligation more economically than wind power system and solar power system at heat supply distance 2km. If the KHNP build the TEs-E BM 2km away from Wolsong NPP site for fulfillment of the RPS obligations, the RPS obligation can be performed 49% more economically than the solar power system and 3% more economically than the wind power system.

For the purpose of finding ways to be able to secure additional economical fulfillment of RPS obligations of the TEs-E BM, sensitivity analysis is carried out. In order to find the factors that have a significant effect on the LCOE, all the factors affecting the LCOE are changed to the same ratio (± 20%) and the sensitivity was analyzed by Oracle Crystal Ball. As a result, Capacity Factor and Capital Investment Cost were found to have a significant impact on LCOE change. If the Capacity Factor is increased by 20%, the LCOE of the TEs-E BM is reduced by 8% to 124.51won/kWh. If the Capital Investment Cost is reduced by 20%, the LCOE of the TEs-E BM is reduced by 5% to 129.39won/kWh. Therefore, in order to secure additional economical fulfillment of RPS obligations of the TEs-E BM, it was confirmed that it is important to increase the Capacity Factor, and to reduce the Capital Investment Cost.

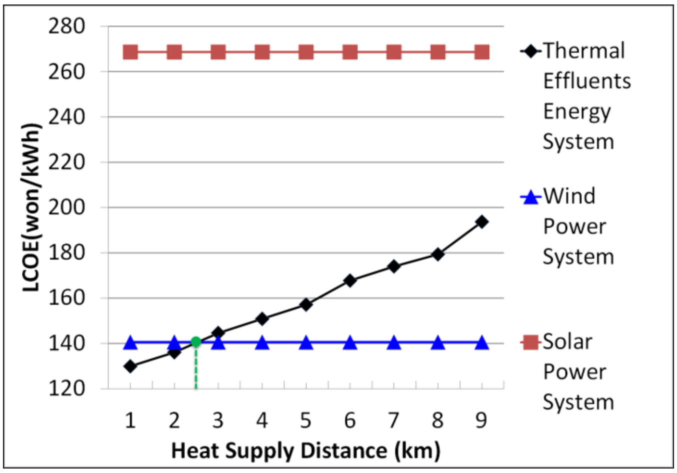

Fig. 6. LCOE of the TEs-E BM according to heat supply distance

Especially, in case of the Capital Investment Cost, the TEs piping construction cost (41.3%) has a great influence. Unlike other factors, since the information gained so far is not sure whether the TEs piping construction cost can be secured additional economical fulfillment of RPS obligations of the TEs-E BM, we analyze additionally the TEs piping construction cost according to heat supply distance. Fig. 6 shows that the LCOE increases by about 5% as heat supply distance of the TEs-E BM increases by 1 km. As a result, the economical fulfillment of RPS obligations of TEs-E BM is secured only within the heat supply distance of 2.5 km for the wind power system.

V. SUGGESTION FOR ACTIVATING THE THERMAL EFFLUENTS ENERGY BUSINESS MODEL OF NPPS

We conducted a study on feasibility of the TEs-E BM of NPPs. Here, there is significance in that this study creates a business model that can be applied immediately to reality in order to activate the utilization of TEs energy of NPPs, and analyze it based on the current laws and support systems, technology and economics to validate the feasibility of developing the TEs-E BM of NPPs.

As a result, if KHNP utilizes the TEs-E BM for the purpose of fulfilling the RPS obligations, it is confirmed that the TEs-E BM of NPPs could perform the RPS obligation more economically than the solar power system and wind power system up to at least 2.5km of the heat supply distance.

However, based on Table 7 and (3), REC approved power generation volume by residential heating and 1.5 weighted farm heating is 20,833,339 kWh, and the fulfillment rate of RPS obligation by the TEs-E BM is only 0.67% of 3,122,315 MWh which is KHNP’s amount of mandatory supply with deferment in 2014. In other words, the problem is that the RPS obligation can be performed economically when using the TEs-E BM, but the status of fulfillment of RPS obligation supply is too small. This is because there is a lack of heat demand compared to rich heat supply. In other words, this is because 1) NPP is located on the coast, 2) the TEs-E BM in which the heat supply distance to ensure the economical fulfillment of RPS obligations is only 2.5 km in radius centered on NPP, and 3) the application field that can be applied to the current support system is agriculture and fishery energy. Therefore, in order to resolve these problems, it is essential to expand the heat supply distance, which ensures the economical fulfillment of RPS obligations of the TEs-E BM, and to expand the utilization field that can benefit from the current support system. Therefore, this study additionally proposes to improve the government's support system related to the utilization field and the expansion of heat supply distance.

The mandatory supplier is also a REC buyer at the same time. So, the economic value of the status of fulfillment of RPS obligation supply that can be secured by the investment of the TEs-E BM can be calculated by the penalty surcharges for RPS failure or the cost of purchasing the REC. On the other hand, the REC transaction is being operated through the Korea Power Exchange (KPX), and the REC unit price changes every month depending on the transaction amount and transaction volume. However, for the ease of analyzing the relative change of the heat supply distance which ensures the economical fulfillment of RPS obligations of the business model according to REC weight, this study assumes that the economic value of the status of fulfillment of RPS obligation supply is the REC sales revenue by applying the REC weight and arbitrary fixed REC unit price (50,000won/REC) instead of the penalty surcharges for RPS failure or the cost of purchasing the REC. Then the REC sales revenue is converted into a present value and reflected in the LCOE* by using (6) and (7).

$$LCOE^{*} = LCOE - \frac{\sum_{t}^{N} \frac{REC_t}{(1+r)^t}}{\sum_{t=0}^{N} \frac{P_t}{(1+r)^t}} \tag{6}$$

$$REC_t = P_t \times REC\ Unit\ Price \times REC\ Weight \tag{7}$$

Where, LCOE*: LCOE with REC sales revenue [won/kWh], r: Discount rate [%], Pt: New & Renewable energy generation in year t [kWh], N: Life time [yr]

By using (6) and (7), we apply the REC weight 1.0 to the wind power system and the solar power system, and the REC weights 0, 1.0, 1.5 and 2.0 to the TEs-E BM regardless of the utilization field to analyze the change of the heat supply distance which ensures the economical fulfillment of RPS obligations of the TEs-E BM.

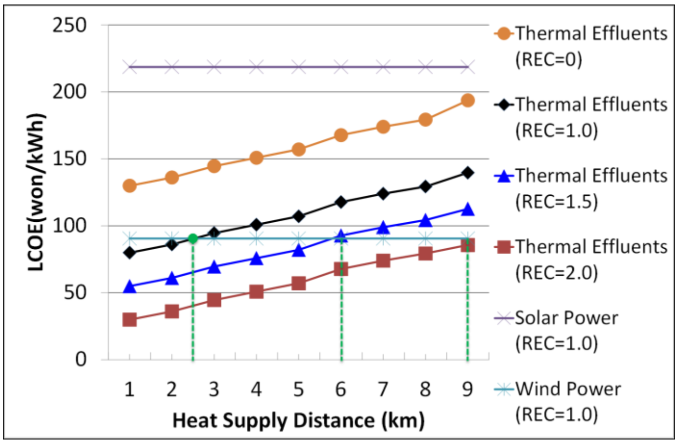

Fig. 7. LCOE* according to heat supply distance

As a result, when the REC weight 1.5 is applied, the heat supply distance to ensure the economical fulfillment of the RPS obligations of the TEs-E BM relative to the comparative system is extended from 2.5km up to 6km. In the same way, when the REC weight 2.0 is applied, it is extended up to 9km. Therefore, the TEs-E BM guarantees the economical fulfillment of RPS obligations up to a heat supply distance of 9km as presented in Fig. 7. This finding shows that the government’s support system for the TEs-E BM should be improved to apply the REC weight differently according to heat supply distance regardless of the utilization field instead of applying the REC weights differently according to the utilization fields. In the end, the higher REC weight regardless of the utilization field is applied to the TEs-E BM than the wind power system and the solar power system, the more the heat supply distance to ensure the economical fulfillment of RPS obligations of the TEs-E BM is increased.

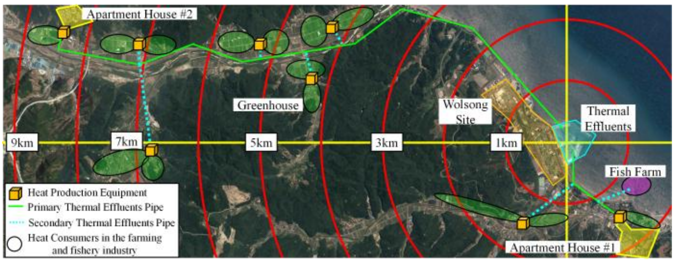

Fig. 8. The concept drawing of extended wide-area complex from the TEs-E BM

Under the assumption that the support system will be improved, we actually try to apply the TEs-E BM to the newly built NPP company housing in Yangbuk-myeon, Gyeongju, which is about 8.5km away from Wolsong NPP site. If the TEs-E BM is gradually expanded to the form of wide-area complex as in Fig. 8, the fulfillment rate of RPS obligation will be increased up to at least 5.78% of 3,122,315MWh which is KHNP’s amount of mandatory supply with deferment in 2014 through the fulfillment of 21,371,000kWh which is applied REC weight 2 for one residential heating and the fulfillment of 158,982,811kWh which is applied REC weight 1.5 or 2.0 applied for 14 farm heating.

This result shows that no matter how we create the validated TEs-E BM internally, there were still limitations in activating the utilization of TEs energy without the externally appropriate support system. Previous studies [6, 27] had a problem in that it only suggested the improvement of the REC weight without improving the utilization field applying the REC weights differently under the current laws and support systems in order to activate the utilization of TEs energy. However, unlike electrical energy, which can be used for long-distance transmission and multipurpose applications, if we consider the nature of TEs energy that is limited only to the area surrounding the power plant and to heating, previous studies are not enough to activate the utilization of TEs energy. Therefore, there is significance in that this study suggests improving the government's support system to apply REC weights differently depending on the heat supply distance, regardless of the utilization field, instead of applying different REC weights depending on the utilization field. By doing so, this finding will overcome the limitation of TEs energy and contribute to the activation of its utilization. In conclusion, we can know that if KHNP builds a company housing based on the TEs-E BM at a proper location, it will contribute greatly to the formation of large-scale TEs energy wide-area complex around NPPs. By establishing the basis for utilizing such TEs energy, KHNP will be able to maximize the status of fulfillment of RPS obligation economically and minimize thermal pollution by consuming abundant heat capacity of TEs. Local residents will also be able to secure price competitiveness for agricultural and fishery products by securing economic heating energy, which will contribute to the development of local economy.

VI. CONCLUSION AND LIMITATIONS

Unlike previous studies, we noticed that NPPs have more favorable environment conditions for TEs energy development than TPPs, and conducted a study on feasibility of the TEs-E BM of NPPs. Here, there is significance in that this study creates the TEs-E BM of NPPs that can be applied immediately to reality in order to activate the utilization of the TEs energy of NPPs, and validate the feasibility of it through analyzing the current laws and support systems, technology and economics, also suggests the improvement of the current support system for activating the TEs-E BM of NPPs. As a result, we could create the TEs-E BM, which has 11.4MW system capacity and guarantees the economical fulfillment of RPS obligations up to a heat supply distance of at least 9km. Moreover, if wide-area complexes are formed by the proposed TEs-E BM at 4 sites of NPPs in Korea, KHNP will be able to achieve the fulfillment rate of RPS obligation of 24% with TE energy. In addition, KHNP will minimize not only thermal pollution, but also waste of energy through maximizing the fulfillment rate of RPS obligation utilizing TEs-E BM. In the end, if the utilization of TEs energy of NPPs is activated based on the application of the improved support system and the validated TEs-E BM, KHNP as well as the neighboring areas will be able to develop a win-win basis. Furthermore, it can be expected to improve the efficiency of energy utilization, replace energy imports, and reduce greenhouse gas emissions nationally.

In addition, the limitations of this study are also recognized. The proposed TEs-E BM proposed s a valid model for only KHNP, which has RPS obligation. Therefore, other business models for a power generation company without RPS obligation require further study. Moreover, analysis of the TEs energy charge considering the position of the consumer who wants to be cheaper than the current heating fuel cost and the position of the supplier who wants a faster return on investment of the TEs-E BM than comparative systems is also needed. Finally, there is a practical limitation that it is impossible to reflect the technical and social conditions due to the lack of a commercialized business case, and differences may occur when applying the research contents to the reality.

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